Implementation of a 500h Engine Test Cycle and Field Testing of DEUTZ-Common-Rail Engines in Heavy-Duty Euro IV Truck Applications for Release of Biodiesel

UFOP Project No. 540/080

– Final Report –

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General Information

DEUTZ AG is an internationally operating, independent company for the development and production of diesel engines for on-road and off-road applications in the 5 to 500 kW range.
For years, one of the key activities of DEUTZ AG has been the development of diesel engines which run on 100 % biodiesel in accordance with EN 14214 [1]. The Technical Circular TR 0199-99-3005 [2] deals in detail with all engine releases for biodiesel applications.

Project presentation

The aim of the project was to implement tests to release the TCD 2013 4V EURO IV engine series with DEUTZ-Common-Rail injection system (DCR©) in commercial vehicles for biodiesel. The scope of testing was defined as follows:

Engine and function tests on the test bench (performance, emissions with diesel fuel and biodiesel)

- 500 h endurance test according to DEUTZ in-house standard SE 0163 5005
- Preliminary inspection function tests (performance, emissions)
  - Measurement of power and consumption on the torque curve
  - Emission measurement in the legally prescribed test cycles (ESC and ETC)
- Daily inspection of the engine condition at nominal power
- after 500 h: Repetition of the function test (performance, emissions)
- In-test lubricating oil analyses
- Appraisal of the engine by DEUTZ
- Appraisal of the injection system by Bosch

Implementation of field tests to verify suitability for biodiesel

- 2 bus engines, IOB Omnibusverkehr GmbH, Ilmenau
- Truck engines were originally planned but were then cancelled by the project partner Volvo
- In-test lubricating oil analyses

This combination of endurance tests on the test bench and in practical use is standard procedure at DEUTZ AG and must be implemented prior to release of new engine concepts and special fuels. The test bench tests are run at a very high engine load and the engine components are subjected to very high stress so that potential weak points can be discovered reliably. Extensive measured values are recorded to diagnose the engine condition, e.g. oil analyses with measured values of abraded metal provide valuable indications of the state of wear of the engine during the endurance test. At the end of the endurance test, the engine is dismantled and the state of wear of the individual components is examined in detail.

Since the test bench has a fixed standard order of procedure, a field test is an important and necessary supplement to the DEUTZ release procedure because the engine operation is much more variable and different climatic conditions can also be tested at the same time.

The measurements for the release of biodiesel described in this report were carried out on a EURO IV bus engine but are also to be transposed for biodiesel releases for EURO V.

Investigation of the effectiveness of the SCR exhaust after-treatment system

- The SCR catalysts of the 2 buses were removed after approx. 70,000 km and measured to assess any impairment.
- Measurement catalyst A:
  - Systematic measurement of the SCR efficiency at different exhaust temperatures and space velocities on the engine test bench
  - Tests of the catalyst activity and measurement of the contamination with potential catalyst poisons at the catalyst manufacturer's
- Measurement catalyst B:
  - Implementation of the legally prescribed test cycles (ESC and ETC) on the test bench after installing the SCR catalyst in an identical engine

Biodiesel sensor

- Measurement of the sensor function in the laboratory with calibration mixtures of diesel fuel and biodiesel.
- Installation of a biodiesel sensor in one of the two field test buses in Ilmenau
- Recording of measuring data and sensor function during the field test
- Re-measurement of the sensor function in the laboratory

With a biodiesel sensor you can measure whether the currently used fuel consists of mineral diesel fuel or biofuel, mixtures can also be quantified with it. If the engine electronics can recognise the type of fuel currently being used it is basically possible to adapt the engine parameters such as injection volume and injection time to the current fuel. It would therefore be possible to compensate the drop in performance with biodiesel and also adapt the NOx emissions to ultimately have no negative but only positive effects with biodiesel. Since DEUTZ has so far no biodiesel sensor in series production, the practicability of a biodiesel sensor which was developed by BERU based on a FAL project [3] but not previously used in series applications was to be tested in the field test. The sensor determines the biodiesel content by measuring the dielectric constant; the fuel temperature is also measured. Both measured values are provided serially by an interface.

The commercial vehicle engine TCD 2013 4V

The TCD 2013 4V series is a water-cooled 4-valve inline engine with DEUTZ Common-Rail injection and without exhaust gas recirculation. The SCR exhaust after-treatment is used to comply with the emission stages EURO IV and EURO V. The 4 and 6 cylinder engines have the following technical data:

	TCD2013 L04 4V	TCD2013 L06 4V
Stroke:	130 mm	130 mm
Bore:	108 mm	108 mm
Displacement per cylinder:	1.19 l	1.19 l
Displacement:	4.76 l	7.14 l
Fuel consumption at rated power:	210 g/kWh	210 g/kWh
Minimum fuel consumption:	198 g/kWh	195 g/kWh
Max. torque:	800 Nm	1,200 Nm
Max. available power:	158 kW/2,300 rpm	235 kW/2,300 rpm (for EURO IV)
Available emission stages:	EURO IV + V	EURO IV + V

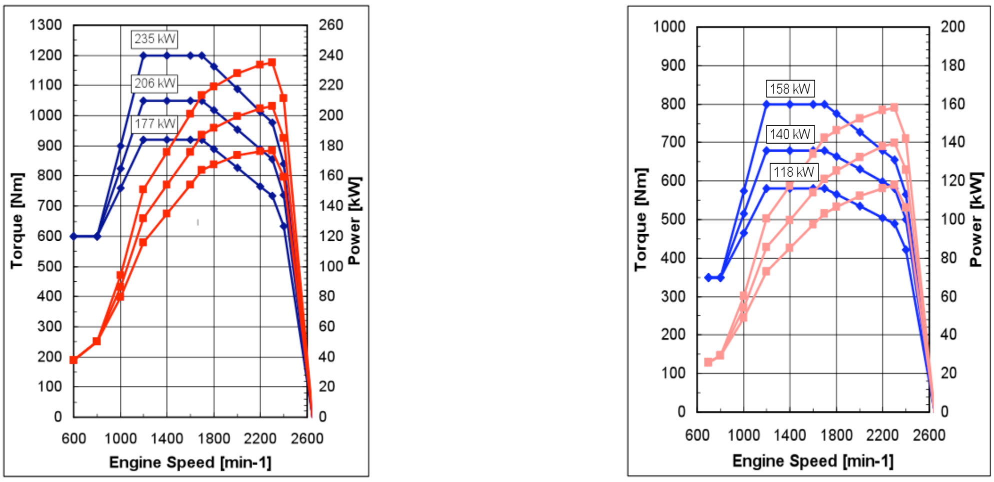


Figure 1: Performance profile 6-cylinder engine / power profile 4-cylinder engine

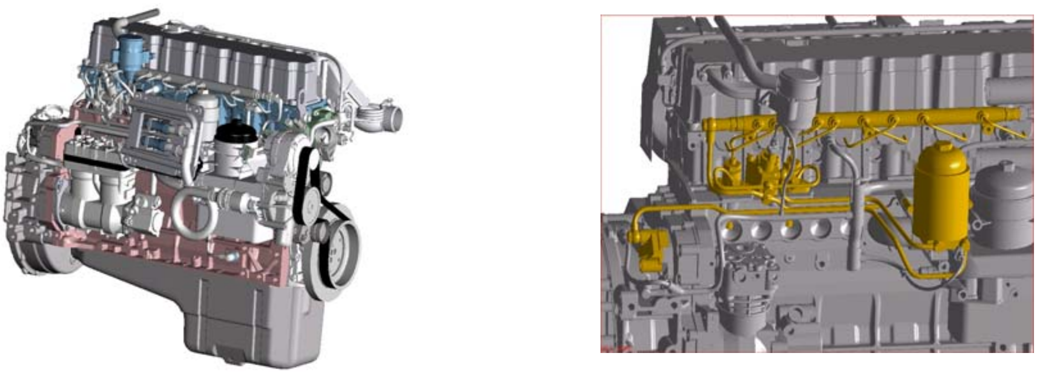


Figure 2: Engine cross-section view with DEUTZ-Common-Rail injection system (DCR©)

Results of the engine and function tests on the test bench

The 500h endurance test was carried out according to DEUTZ in-house standard SE 0163 5005 [4]. It is a test bench program with high portions of full load and even with overload. In addition to daily inspection of the engine condition at the begin and at the end of the test program detailed measurements of performance and emissions with Biodiesel and with standard Diesel fuel took place. At the end, the engine was appraised and the injection system analysed by DEUTZ and Bosch respectively.

The daily inspection revealed no irregularities. Performance reductions of approximately 9% in comparison with diesel operation were detected in the torque curve in the performance tests before and after the endurance test. The specific consumption increased with biodiesel by approximately 12 weight%.

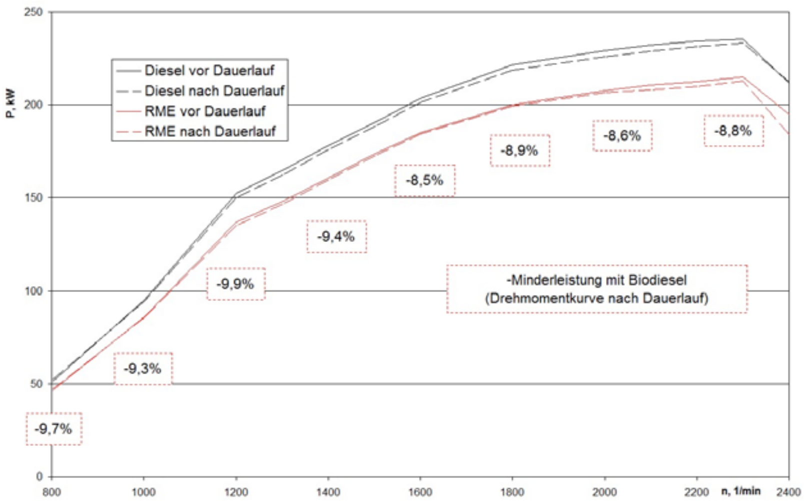


Figure 3: Engine performance of Diesel/FAME before and after the 500h endurance test

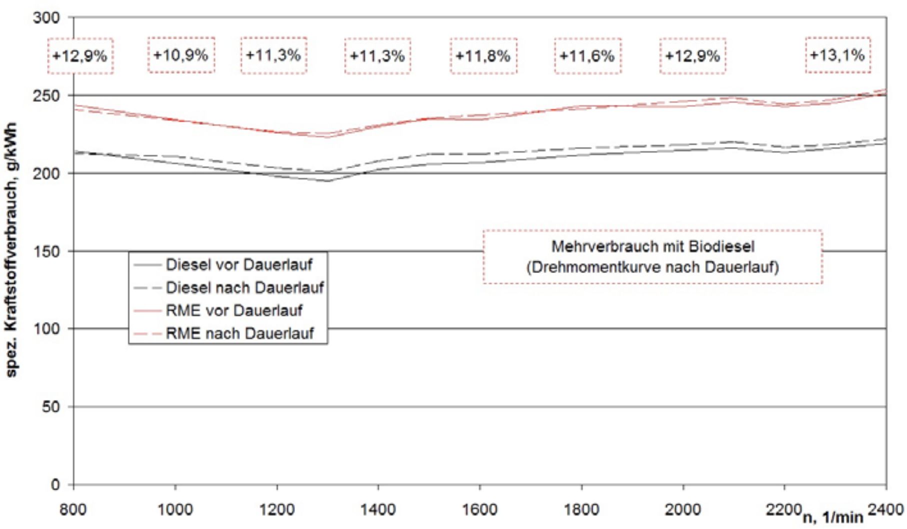


Figure 4: Specific consumption of Diesel/FAME before and after the 500h endurance test

The lower performance and higher consumption with biodiesel can be explained by the lower calorific value and the higher density. The measured differences in comparison with diesel fuel are within the expected range. The performance and consumption values for both biodiesel and diesel fuel are practically the same after the endurance test as in the measurements made before the endurance test, i.e. the biodiesel operation has not changed any of the important engine parameters.

The engine was measured before the endurance test with FAME and diesel in the ESC cycle (European Steady Cycle) and after the endurance test additionally in the ETC cycle (European Transient Cycle). As far as emissions are concerned, lower values are measured for the CO, HC and particle emissions. Especially the soot emissions which account for a large part of the particle emissions are reduced considerably by biodiesel (up to 66 %!). This positive aspect of the biodiesel is due to the oxygen content of the molecules which reduces the formation of soot always associated with a local lack of oxygen. The NO_x emissions, on the other hand, are increased, in the stationary ESC by approximately 10 % and in the transient ETC by approximately 20 % even. The higher NO_x emissions with biodiesel can be explained by the higher combustion chamber temperatures due to the oxygen content of the molecules.

The 500h endurance test with biodiesel has no negative effect on the emission values. The measured values even reveal a slight reduction in the emissions.

		Test power	Nitrogen oxides	Hydro-carbons	Carbon monoxide	Particulate Matter	Soot
		kW	g/kWh	g/kWh	g/kWh	mg/kWh	mg/kWh
European Steady State Cycle, ESC							
before endurance test	Diesel	116,1	8,30	0,059	0,181	19,7	7,0
	FAME	106,2	9,35	0,026	0,157	15,9	3,0
	Diff, %	**-8,5**	**12,6**	**-55,9**	**-13,3**	**-19,3**	**-57,1**
after endurance test	Diesel	115,8	8,06	0,038	0,175	19,5	9,0
	FAME	105,6	8,70	0,018	0,167	14,9	3,0
	Diff, %	**-8,8**	**8,0**	**-52,6**	**-4,6**	**-23,8**	**-66,7**
% change after/before	Diesel	-0,3	-2,9	-35,6	-3,3	-1,0	28,6
	FAME	-0,6	-6,9	-30,8	6,4	-6,3	0,0
European Transient Cycle, ETC							
after endurance test	Diesel	70,4	8,83	0,085	0,96	26,4	19,0
	FAME	63,74	10,75	0,034	0,45	15,2	6,5
	Diff, %	**-9,5**	**21,7**	**-60,0**	**-53,1**	**-42,4**	**-66,0**

Figure 5: Emission measurement in the ESC and ETC test of Diesel/FAME before and after the 500h endurance test

The final engine evaluation and analysis of the injection system by DEUTZ and Bosch revealed no irregularities but Bosch have issued no series release for FAME operation so that DEUTZ has to take over the risk of quality costs.

Field tests for verification of biodiesel suitability

The field tests were carried out at the Ilmenau bus company in two city buses of the Volvo 8700 RLE type (TCD 2013 L06 4V, IK-OV 78 (engine no. 10259324) and IK-OV 79 (engine no. 10259325).

The buses were used exclusively in city bus operation with biodiesel according to DIN EN 14214 and driven approx. 100,000 km.

Figure 6: Biodiesel testing in city bus operation

There were only slight irregularities during the field tests. Because the elastomeric parts in the fuel line between the fuel supply pump and the control unit were not resistant, these were replaced by biodiesel-resistant pipes in both buses after approximately 30,000 km.

These fuel pipes have since been introduced into the series. Damage to the paintwork due to splashing with biodiesel was also discovered.

Figure 7: Damaged paintwork on the engine

The two exhaust after-treatment systems were removed after approx. 70,000 km and assessed by DEUTZ and the catalyst manufacturer Johnson Matthey. The SCR-CAT of IK-OV 78 was replaced by a new catalyst, in the second bus IK-OV 79 the removed SCR system was re-installed and used until the end of the field test.

The originally planned testing of 3 truck engines was postponed by the project partner Volvo because of the current economic situation and technical problems (no biodiesel in North Sweden, poor climatic conditions for the use of biodiesel).

Lubricating oil analyses during the field test

Samples of the lubricating oil were taken from both engines at regular intervals and all typical used oil parameters analysed in DEUTZ's oil laboratory. The analyses were conducted according to the currently recognised DIN test methods.

TCD2013L06-4V	Run time engine, km		7682	17060	28432	46004	59132	78076	93700	Deutz limit
SN. 10259324	Run time oil, km		7682	17060	28432	13419	26619	16433	32057	
FAME content	% mass	Infrared method	1,9	4,1	8,1	8,4	14,8	9,8	16,3	10
Viscosity,100°C	mm²/s	EN ISO 3104	11,3	10,62	8,72	10,39	9,1	10,09	9,52	9,3 (15W.)
Soot	% mass	DIN 51452	< 0,1	0,17	< 0,1	< 0,1	< 0,1	< 0,1	< 0,1	3,0
Silicon	mg/kg	DIN 51396-1	36,1	44,7	41,3	7,2	8,5	5,4	8,6	20
Iron	mg/kg	DIN 51396-1	19,1	27,3	35,4	6,4	10,8	11,1	23,9	150
Lead	mg/kg	DIN 51396-1	1,8	3,4	11,4	2,2	3,3	5,4	38,5	30
Copper	mg/kg	DIN 51396-1	7,4	15,3	29,3	3,5	6,6	5,9	12,7	20
Chromium	mg/kg	DIN 51396-1	1,8	2,6	3,9	< 0,1	0,5	2,2	3,4	20
Aluminium	mg/kg	DIN 51396-1	1,8	3,9	7	0,7	3,4	2,9	4,2	25
Sodium	mg/kg	DIN 51396-1	4,8	6,3	8,5	2,6	3,4	8,5	10	

TCD2013L06-4V	Run time engine, km		1486	20799	30340	43900	57729	78723	95878	Deutz limit
SN. 10259325	Run time oil, km		1486	20799	30340	8630	22459	18034	35189	
FAME content	% mass	Infrared method	0,2	5	8,6	5,9	12,6	10,9	12,9	10
Viscosity,100°C	mm²/s	EN ISO 3104	11,78	10,56	9,92	11,12	9,44	9,78	9,79	9,3 (15W..)
Soot	% mass	DIN 51452	< 0,1	< 0,1	< 0,1	< 0,1	< 0,1	< 0,1	< 0,1	3,0
Silicon	mg/kg	DIN 51396-1	19,2	34,5	31,3	4,3	5,8	4,9	5,3	20
Iron	mg/kg	DIN 51396-1	6,6	20,6	26,5	1,7	8,6	9,2	15,2	150
Lead	mg/kg	DIN 51396-1	1	3,1	9,4	2,1	2,6	5,2	14	30
Copper	mg/kg	DIN 51396-1	6,1	18,4	27,4	< 0,1	5,7	4,8	7,7	20
Chromium	mg/kg	DIN 51396-1	0,5	2,2	3,2	< 0,1	0,3	1,5	1,9	20
Aluminium	mg/kg	DIN 51396-1	1,1	3,3	4,8	< 0,1	0,9	2,3	2,6	25
Sodium	mg/kg	DIN 51396-1	5,2	6,8	14,4	2,6	3,8	4,4	4,5	

Engine Oil: Agip Sigma TFE 10W-40, kinematic viscosity of fresh oil: 14,4 mm²/s

Figure 8: Oil analyses field test engines (oil quality DQC III-05)

The DEUTZ used oil limit values are specified on the right of the table. Measured values which exceed these limit values are colour-highlighted depending on how far they exceed the limits.
Increased silicon percentages are noticeable in both engines up to the first oil change after approx. 30,000 km (DEUTZ limit value: 20 mg/kg). These values are a familiar phenomenon in new engines and can be explained by the so-called original soiling (casting residue, residue from mechanical processing).

The increased silicon values were only found in the first oil change and not at the second and third oil change intervals. The increased copper values during the first oil change are also associated with the wear due to original soiling.
The main problem with biodiesel operation, however, is an increased contamination of the engine oil by FAME and considerably reduced viscosities as a result. The DEUTZ limit value of 10 vol-% biodiesel infiltration was exceeded. The relatively high FAME contamination into the lubricating oil can be explained especially by the low load city bus operation; the FAME contamination in the high load endurance test was only approx. 2 vol-%. The biodiesel contamination can lead to chemical reactions and polymerisations in the engine oil with consequential engine damage. For this reason, a halving of the oil change intervals is prescribed for biodiesel operation; in the case of the bus engines described here, the standard interval is reduced from 30,000 km to 15,000 km.

Examination of SCR exhaust after-treatment systems after the field test

Examination of the 1st SCR catalyst

The efficiency of the SCR system was measured at different temperatures and space velocities. The results are shown in figure 9 for a catalyst temperature of 280 °C, in figure 10 for a catalyst temperature of 330 °C and in figure 11 for a catalyst temperature of 450 °C.

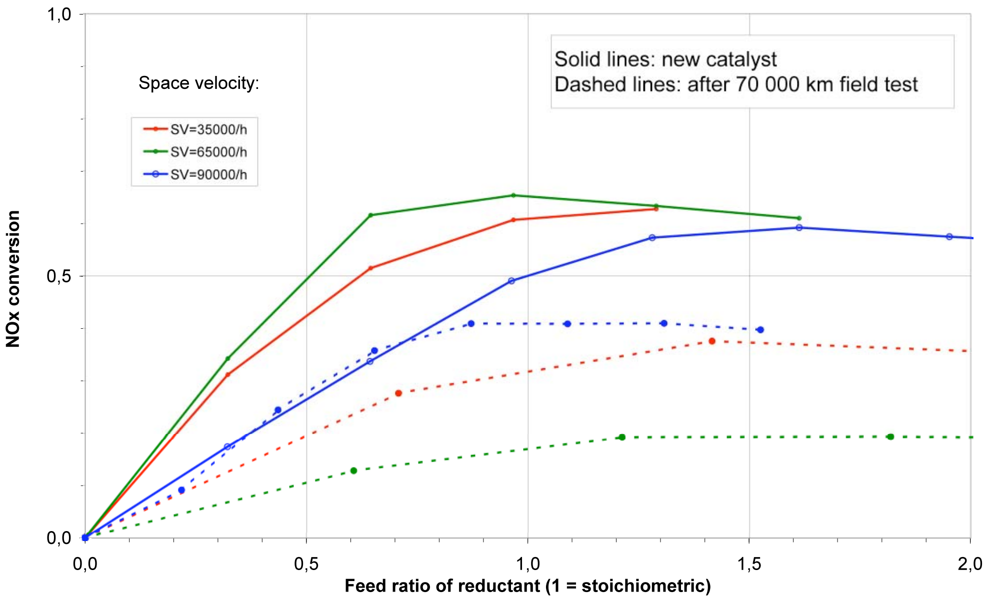


Figure 9: SCR efficiency at 280 °C SCR catalyst inlet temperature

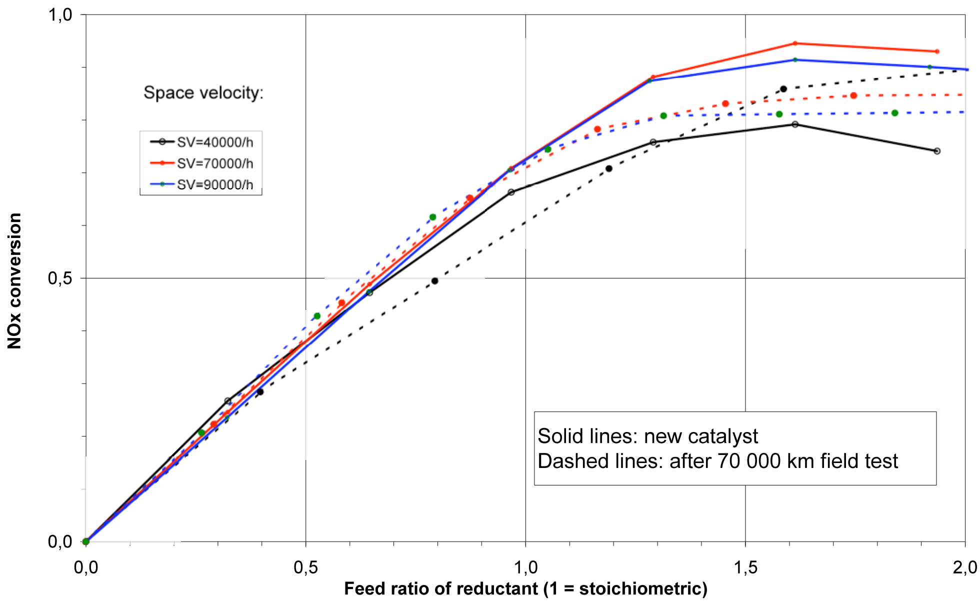


Figure 10: SCR efficiency at 330 °C SCR catalyst inlet temperature

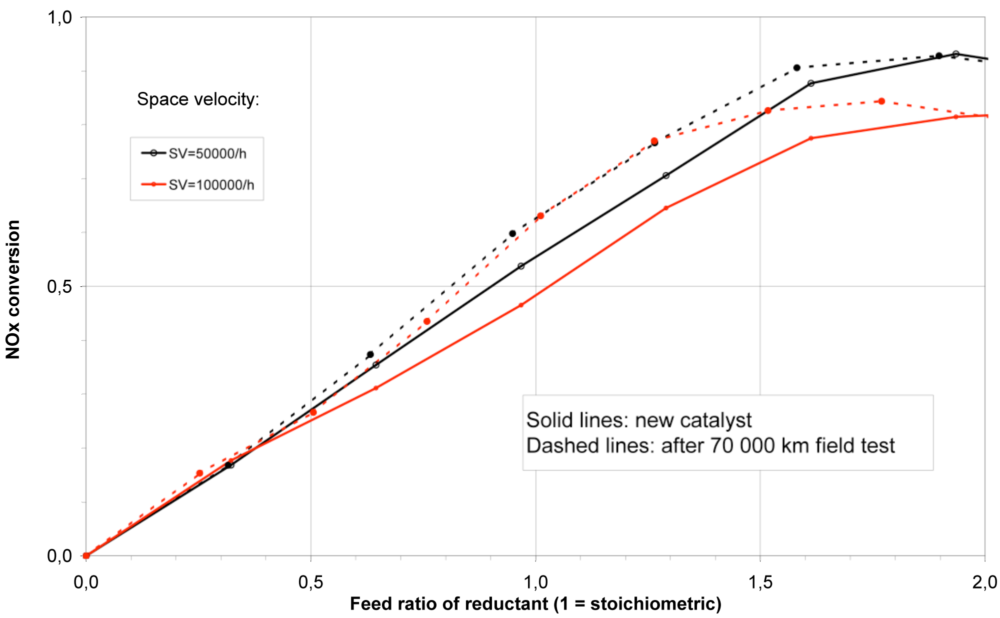


Figure 11: SCR efficiency at 450 °C SCR catalyst inlet temperature

Whilst the efficiencies for field test catalyst 1 remained largely unchanged at the temperatures of 330 and 450 °C in comparison with a new catalyst, greatly reduced efficiencies of approx. 50% can be observed at the lower exhaust temperature of 280 °C.

At first it was assumed that this drop in the efficiency could be due to potassium and sodium which are found in biodiesel and which are known to be able to poison SCR catalysts. However, it was revealed in the course of the measurements that the full effect of the catalyst could be restored after the catalyst had been exposed to high exhaust temperatures for a longer period of time. Since a chemical poisoning by inorganic elements such as potassium and sodium cannot be reversed by high temperatures, another explanation had to be found for the drop in low temperature activity: Coking of unburned biodiesel components had probably taken place on the SCR catalyst due to the low load and low exhaust temperature during the bus field test. Such coking is more likely with biodiesel than with diesel fuel because of the reactive double bonds in the molecule.

Examination of the 2nd SCR catalyst

The 2nd catalyst was also tested at different exhaust temperatures and space velocities for the efficiency of the nitrogen oxide reduction but operated for 5 hours at full load first. This catalyst showed no signs of efficiency losses even at the lower tested exhaust temperature of 250 °C:

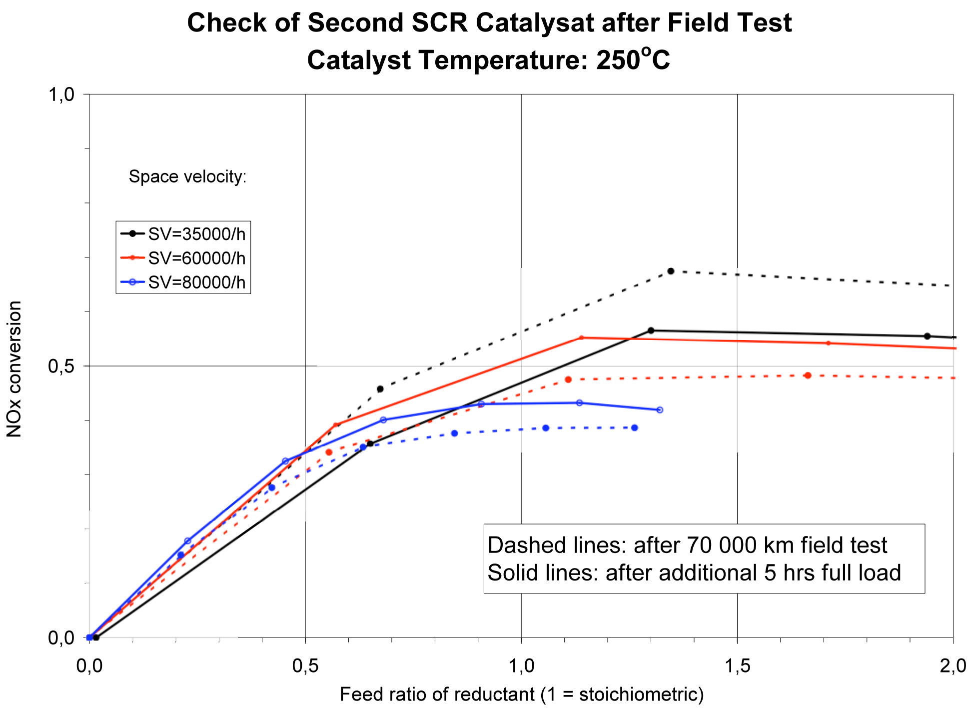


Figure 12: SCR efficiency at 250 °C SCR catalyst inlet temperature

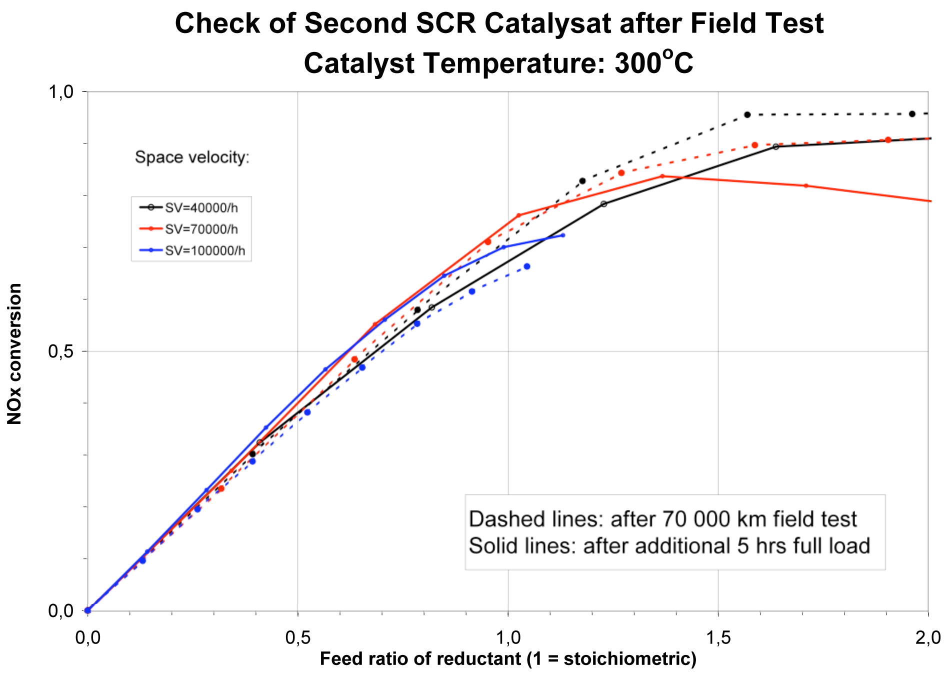


Figure 13: SCR efficiency at 300 °C SCR catalyst inlet temperature

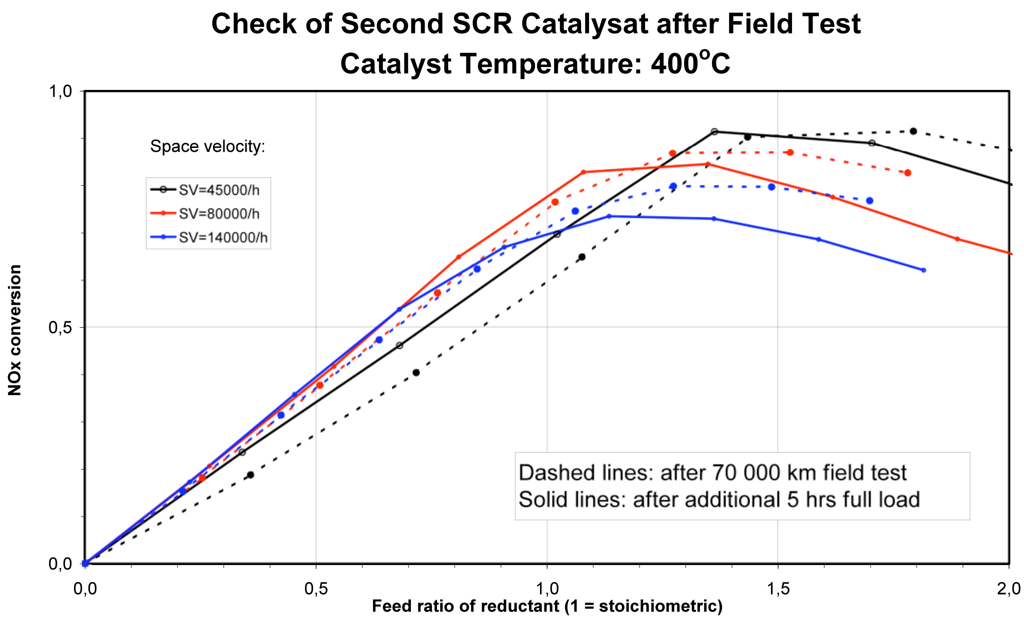
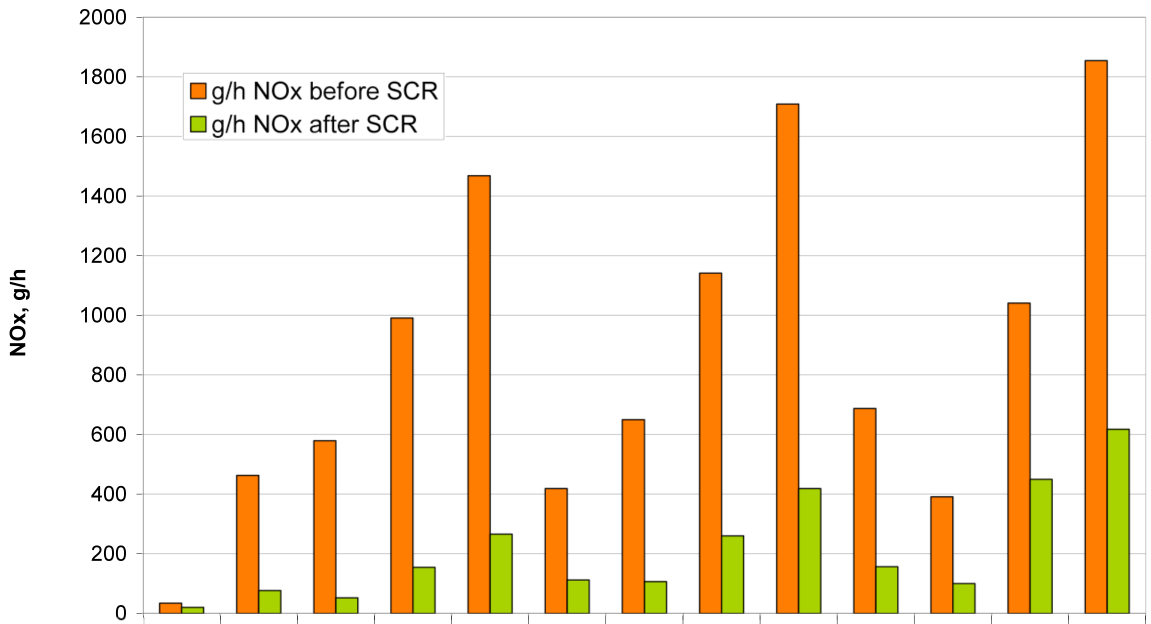


Figure 14: SCR efficiency at 400 °C SCR catalyst inlet temperature

In addition to the systematic tests of the SCR efficiency, the emissions after SCR catalyst in the ESC test were measured to check compliance with the EURO V limit values. A NO_x emission of 1.80 g/kWh was measured and therefore well below the limit value of 2.0 g/kWh:

	Nitrogen oxides NOx g/kWh	Hydro-carbons HC g/kWh	Carbon monoxide CO g/kWh
before SCR catalyst	7,35	0,025	0,096
after SCR catalyst	1,80	0,01	0,065
SCR catalyst efficiency, %	**-75,5**	**-60,0**	-32,3

Figure 15 below shows the NO_x emissions before and after the catalyst and the SCR efficiencies for the 13 operating points of the ESC:



ESC speed	Idle	A	A	A	A	B	B	B	B	C	C	C	C
Load, %	0	25	50	75	100	25	50	75	100	25	50	75	100
Space vel, 1/h	10000	45000	70000	95000	115000	65000	95000	125000	150000	115000	80000	150000	170000
Exh. Temp.°C	143	317	399	435	457	310	356	417	505	352	292	434	506
NOx conversion, %	0	83	90	84	81	73	83	77	75	77	74	56	66

Figure 15: NO_x emissions before and after the catalyst as well as the SCR efficiencies in the ESC

Danger of poisoning of SCR catalysts by potassium and sodium

The SCR exhaust after-treatment is the first choice technology for the reduction of nitrogen oxide emission in EURO IV and EURO V. Here, certain inorganic elements with basic properties, and especially potassium and sodium, are suspected of neutralising the reaction centres of the SCR catalyst and thus worsening the efficiency.

Various projects on the topic of catalyst poisoning and deactivation are being carried out at FVV at the moment [5,6]. The literature also deals with the poisoning of SCR catalysts by metals and especially basic elements such as potassium and sodium exhibit a high poisoning effect:

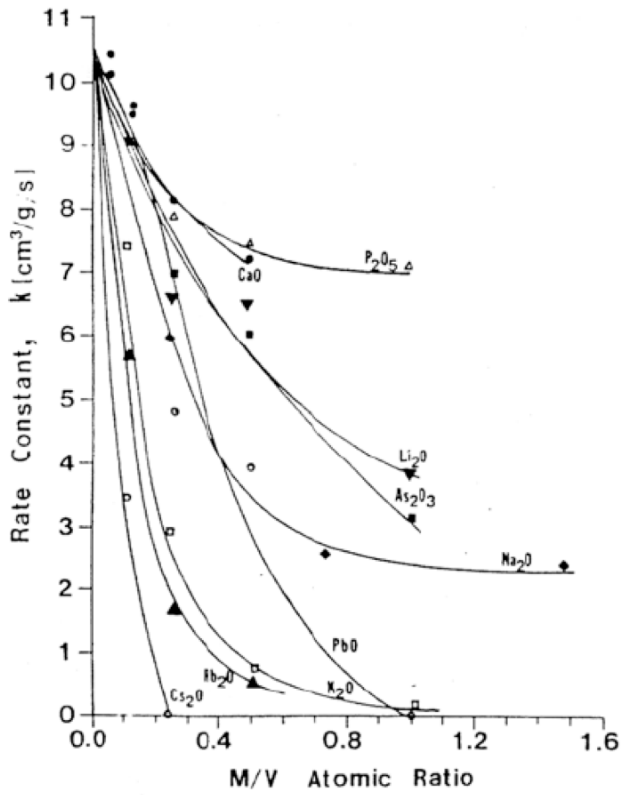


Figure 2.5 Activities of 5% V_2O_5/TiO_2 doped with different amount of metal oxide poisons
M=metal, 300 °C, O_2= 2%, NO=NH_3=1000 ppm, N_2= balance, GHSV=15000hr^{-1}
(Chen and Yang, 1990)

Figure 16: Influencing of the SCR efficiency by different catalyst poisons [7]

An attempt was made to estimate how great the risk of SCR poisoning by biodiesel is based on the knowledge of SCR poisoning in the available literature, the amounts of poisonous components in the SCR catalysts in the field test and the amounts of poisonous components found in the biodiesel used in the field test. A method of calculation was applied here in which the emissions of the elements were calculated within a certain operating time from the element concentrations in the operating media (fuel and lubricating oil) and from the consumptions of these operating media, and in a second step the accumulation of these elements in the wash coat of the catalyst was calculated, based on the assumption of a retention factor of 10%. The following calculation was made for the 70,000 km field test and also contains the element concentrations of 3 biodiesel samples which were taken during the field test.

Field test TCD2013L06-4V (Bus, IOV) for Biodiesel release

Accumulation of poisons K, Na, Ca and Mg in SCR catalyst

Vehicle speed, km/h	**25**
Mileage, km	**70000**
Operation time, h	**2800**

		Unit	Value	Sample 1	Sample 2	Sample 3
Engine	Engine power	kW	213			
	Average engine load	%	20			
Fuel	Fuel consumption	g/kWh	248,6	Biodiesel analysis		
	Fuel consumption, absolute	kg/h	10,6	Sample 1	Sample 2	Sample 3
	Sodium content fuel	mg/kg		**0,27**	**0,28**	**1,33**
	Potassium content fuel	mg/kg		**0,44**	**0,87**	**0,89**
	Calcium content fuel	mg/kg		**0,14**	**0,16**	**0,22**
	Magnesium content fuel	mg/kg		**0,13**	**0,14**	**0,19**
	Phosphor content fuel	mg/kg		**0,40**	**1,80**	**0,16**
Lube oil	Oil consumption	% of fuel consumption	0,05			
	Calcium content lube oil	mg/kg	4000			
	Phosphor content lube oil	mg/kg	1200			
	Oil consumption absolute	g/h	5,30			
Element intake into catalyst, mg/h				Calculation results mg/h		
Na	Sodium from fuel	mg/h		**2,9**	**2,9**	**14,1**
K	Potassium from fuel	mg/h		**4,7**	**9,2**	**9,4**
Ca	Calcium from fuel	mg/h		**1,5**	**1,7**	**2,4**
Ca	Calcium from lube oil	mg/h			**14,8**	
P	Phosphorus from fuel	mg/h		**4,2**	**19,1**	**1,7**
P	Phosphorus from lube oil	mg/h			**4,4**	
Washcoat mass SCR catalyst		g	3110			
Element retention within SCR washcoat		%	10	Calculated % Na... in washcoat		
Na	Sodium im SCR washcoat after 70000 km	% mass		**0,03**	**0,03**	**0,13**
K	Potassium im SCR washcoat after 70000 km	% mass		**0,04**	**0,08**	**0,08**
Ca	Calcium im SCR washcoat after after 70000 km	% mass		**0,15**	**0,15**	**0,15**

Figure 17: Calculation of the accumulation of different elements in the SCR catalyst in the bus field test

Concentrations of 0.03-0.13 weight-% Na and K occur in the wash coat. This is slightly lower on average than the element percentages of Na and K actually analysed in the wash coat of the field test catalyst 1 which were approx. 0.1 weight-%.

It must also be mentioned that analyses of three fuel samples of the used biodiesel exhibited relatively low values for potassium and sodium (respectively 0.3–1.3 mg/kg), i.e. well below the limit value.

The following table shows the same calculation but this time for the less favourable conditions in truck operation with a higher load and longer operation of 500,000 km.

Accumulation of poisons K, Na, Ca and Mg in SCR catalyst
Extrapolation to 500000 km Truck operation with Biodiesel

Vehicle speed, km/h	**65**
Mileage, km	**500000**
Operation time, h	**7692**

				Biodiesel analysis		
				Sample 1	Sample 2	Sample 3
Engine	Engine power	kW	213			
Engine	Average engine load	%	45			
Engine	Fuel consumption	g/kWh	248,6			
Engine	Fuel consumption, absolute	kg/h	23,8			
Fuel composition	Na, Sodium	mg/kg		**0,27**	**0,28**	**1,33**
Fuel composition	K, Potassium	mg/kg		**0,44**	**0,87**	**0,89**
Fuel composition	Ca, Calcium	mg/kg		**0,14**	**0,16**	**0,22**
Fuel composition	Mg, Magnesium	mg/kg		**0,13**	**0,14**	**0,19**
Fuel composition	P, Phosphorous	mg/kg		**0,40**	**1,80**	**0,16**
Lube oil	Oil consumption	% of fuel consumption	0,05			
Lube oil	Calcium content lube oil	mg/kg	4000			
Lube oil	Phosphor content lube oil	mg/kg	1200			
Lube oil	Oil consumption absolute	g/h	11,91			
Element intake into catalyst, mg/h				Calculation results mg/h		
Na	Sodium from fuel	mg/h		**6,5**	**6,6**	**31,7**
K	Potassium from fuel	mg/h		**10,5**	**20,7**	**21,2**
Ca	Calcium from fuel	mg/h		**3,4**	**3,7**	**5,3**
Ca	Calcium from lube oil	mg/h			**33,4**	
P	Phosphorus from fuel	mg/h		**9,5**	**42,9**	**3,8**
P	Phosphorus from lube oil	mg/h			**10,0**	
Washcoat mass SCR catalyst		g	3110			
Element retention within SCR washcoat		%	20	Calculated % Na... in washcoat		
Na	Sodium im SCR washcoat after 700000 km	% mass		**0,32**	**0,33**	**1,57**
K	Potassium im SCR washcoat after 700000 km	% mass		**0,52**	**1,03**	**1,05**
Ca	Calcium im SCR washcoat after after 700000 km	% mass		**1,82**	**1,84**	**1,91**

Angaben Umicore für Washcoatmengen:
Allgemein:10-200 g/l
DOC, DPF : < 100 g/l
SCR : 100-200 g / l

Volumen SCR-Katalysator	l	12,44
Washcoat-Menge SCR-Katalysator	g/l	250
Masse Washcoat SCR-Katalysator	g	3110

Figure 18: Calculation of the accumulation of different elements in the SCR catalyst in truck operation

Whilst the calculation results for the 70,000 km bus operation can be seen as inconspicuous, the same cannot be said for truck operation over 50,000 km. Based on the results found in the literature, a considerable SCR deactivation is to be expected for the calculated accumulated element quantities over such a long period of operation. However, it should also be pointed out that not all the assumptions made for the calculation are verified, especially the retention rate of the elements in the catalyst is merely an estimate and the element contamination was only measured by fuel analyses with 3 random samples and not in more detail. The fact that no concrete cases of poisoning of SCR catalysts in commercial vehicles with biodiesel operation have been found to date gives us reason to hope that catalyst poisoning does not occur in practice to the extent that it seems possible based on the results of the test results and calculations described here.

Nevertheless there is a need for further research here to ultimately ensure that inorganic elements from the biodiesel do not lead to permanent damage of the exhaust after-treatment and thus to non-compliance with emission limits over the whole engine life cycle.
A further reduction in the decisive inorganic ingredients (Na, K, P, Ca, Mg) and adaptation of the existing standard EN 14214 is absolutely essential to reduce the potential risk [8,9]. Adaptation of the appropriate test methods will be necessary, however, to allow the precision data at the lower limit values to be validated at all [10].

Biodiesel sensor

The sensor functions were tested in the laboratory with calibration mixtures of diesel fuel and biodiesel. Then the sensor was installed in one of the two field test buses in Ilmenau and the measured data were recorded during the field test. After the sensor initially showed correct values for the biodiesel concentration (approximately 100 vol.-%) and temperature (30-40 °C), implausible values and abrupt jumps were observed in the further course of operation. Further laboratory tests could not be conducted due to the defective sensor.

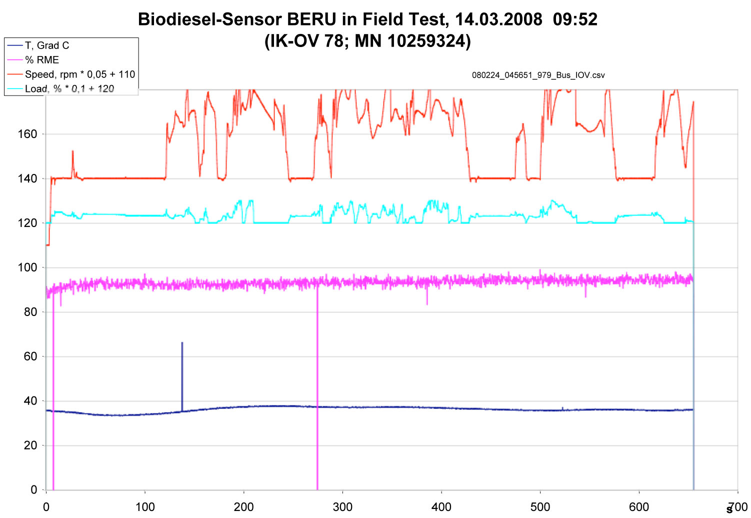


Figure 19: Sensor signals okay (100 % biodiesel operation is detected correctly)

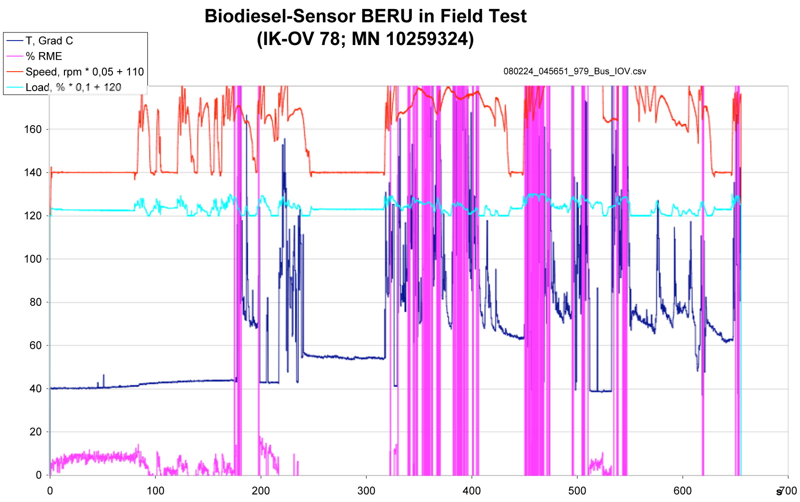


Figure 20: Sensor signals faulty, measured values nonsense

Summary

Although release of the commercial vehicle engine TCD2013 L04/06-4V for operation with 100 % biodiesel (B100) would be possible as far as the basic engine is concerned, the complete EURO IV/EURO V system including the exhaust after-treatment and OBD system cannot be released at present for the following reasons:

- Possible SCR poisoning by potassium and sodium
    - Although the tests carried out have revealed no direct evidence of poisoning, a significant poisoning cannot be ruled out for longer operating times on the basis of the tests and calculations made here.

- Problems with OBD
    - The OBD system can produce error messages in biodiesel operation which are based on the existing reduced performance. This knowledge does not originate from the field test with the bus engines but from basic tests on trucks. To rule out these error messages, a sensor would have to detect that biodiesel is being used. However, a biodiesel sensor is not yet available in series. It was also determined in the tests that the OBD error does not occur with a 30 % biodiesel mixture.

For operation with 30 % biodiesel (B30) the commercial vehicle engine TCD2013 L04/06-4V has been released, but under the premise that the SCR catalyst must be changed every 200,000 km.

The following basic conditions must be observed:
A reduction in performance of approx. 9% has to be accepted when using FAME. Adaptation of the amount of injected fuel is not permissible. Paint damage when splashed with FAME is to be tolerated. Because of the increased biodiesel contamination of the engine oil at low load, the oil change interval must be halved (in tractors from 500 to 250 h, in city bus operation from 30,000 to 15,000 km, in truck operation from 60,000 km to 30,000 km). The use of FAME-resistant components in the fuel system is presumed. A minimum cold starting temperature of –15 °C is defined.

The following points have to be resolved in order to obtain release for the commercial vehicle engines with 100% biodiesel in future:

- Response of the OBD due to reduced performance in biodiesel operation
- Series compatibility of biodiesel sensors
    - Biodiesel sensors can only be omitted in DEUTZ's opinion up to a FAME percentage of 30 vol-% (B30).
- Diesel catalyst deactivation by alkali elements and other catalyst poisons
- DPF loading by ash-forming elements

The releases described here have been added to the new version (8th edition) of the Technical Circular TR 0199-99-3005 "Fuels" to be published in February 2010.

Literature list

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(Fuels for motor vehicles – Fatty Acid Methyl Ester (FAME) for diesel engines – Requirements and test methods)
Beuth Verlag, Berlin (Edition November 2003)

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[3] Munack et al:
Erkennung des RME-Betriebes mittels eines Biodieselkraftstoff-Sensors
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FAL report), special publication 257, Braunschweig (2003)

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DEUTZ Documentation, Edition Nov. 2005

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(Use of a combustion engine in an agricultural application using biofuels with the example of a 4-stroke diesel engine based on present and future exhaust emission directives)
Rheinische Fachhochschule Cologne, diploma dissertation 2008

[9] Munack et al:
Bestimmung der Emissionen und der Partikelgrößenverteilung (Feinstaub) im Abgas eines modernen Euro-IV-Nutzfahrzeugmotors mit SCR-Abgasreinigung im Betrieb mit Biodiesel
(Determination of the emissions and particle size distribution (fine dust) in the exhaust gas of a modern Euro-IV commercial vehicle engine with SCR exhaust cleaning in operation with biodiesel)
FAL Final report, Braunschweig/Coburg (2006)

[10] Draft DIN EN 14214:
Kraftstoffe für Kraftfahrzeuge – Fettsäure-Methylester (FAME) für Dieselmotoren – Anforderungen und Prüfverfahren.
(Fuels for motor vehicles – Fatty Acid Methyl Ester (FAME) for diesel engines – Requirements and test methods)
Beuth Verlag, Berlin (Draft September 2009)